GOES-VW Free-Flyer Concept for Space Weather Instruments

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LASP

Orbital ATK

Assurance Technology Corp

LOCKHEED MARTIN

UCLA

NSO

From the April 2015 GOES-VW Workshop

GOES Next

(Still tentative)

- First assessment: Where does it make the most sense to put various weather and space weather sensors?
  - Should the solar observing sensors go on a different satellite?
- If there is going to be a GOES VW series of satellites, the first satellite should be launch ready in the 2025-2028 timeframe

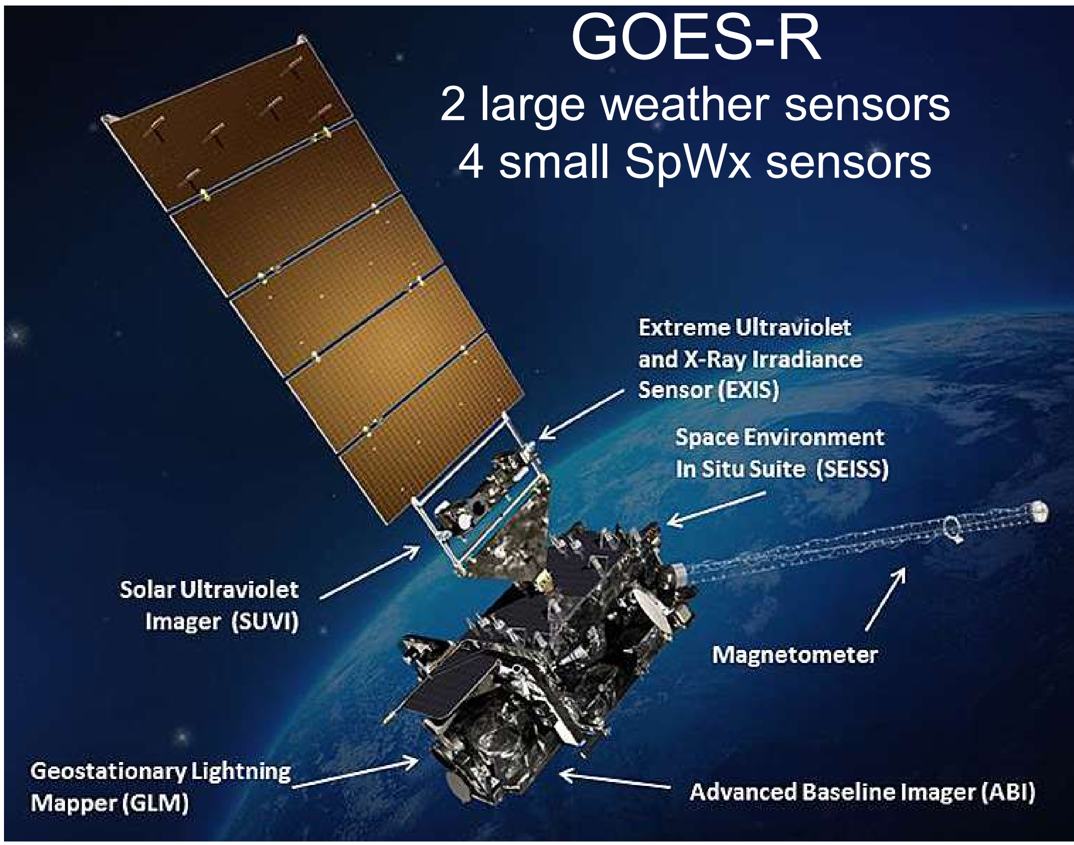
(excerpted from Rodney Viereck's introduction to workshop)

Outline

- Motivations for GOES-VW Free-Flyer for Space Weather Operations
- Mission Concept
- Instruments for GOES-VW
- Spacecraft Concept for GOES-VW Free-Flyer
- Management Plan
- Summary & Recommendations

Space Weather Instrumentation on GOES-R

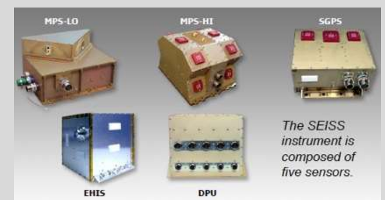
- NOAA's space weather sensors have flown on GOES satellites since the 1970s.
  - The primary (higher priority) GOES instruments are Earth-viewing ***weather sensors that require three GOES spacecraft in-orbit at all times*** (east, west, backup).
  - The ***current GOES spacecraft are complex*** in having large nadir-viewing weather sensors and the small space weather (SpWx) sensors distributed all over the spacecraft, including a large solar-pointing platform on the articulated solar panels.



GOES Space Weather Sensors

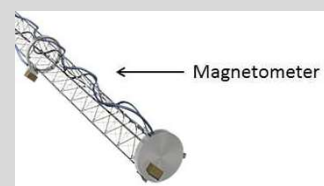
EXIS
Solar EUV & X-ray Irradiance

SEISS
In-situ Energetic Electrons & Protons



SUVI
Solar EUV Imager

Magnetometer & Boom
In-situ Magnetic Field



Figures are from GOES-R Fact Sheets

Key Motivation for GOES SpWx Free-Flyer

Large, higher-priority
Terrestrial
Weather
Instruments

Small, lower-priority
Space
Weather
Instruments

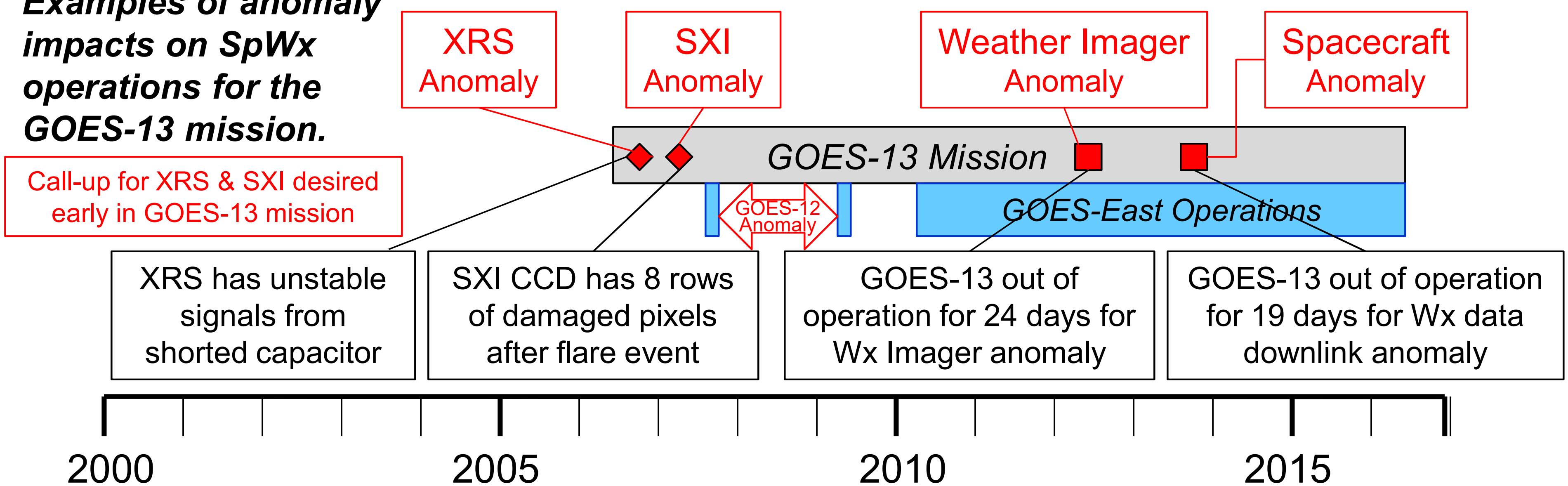
Key Motivation: Continuous High-Quality Space Weather Measurements.

- Current configuration with GOES is not best for achieving this goal.
- ***SOLUTION: Decouple space weather and terrestrial weather operations by having them on independent spacecraft.***

Benefits of Free-Flyer: Greater flexibility to prevent gaps of the space weather monitors

Separation of Weather and SpWx sensors on different spacecraft provides greater flexibility and lower risk for the continuity of SpWx observations.

Examples of anomaly impacts on SpWx operations for the GOES-13 mission.

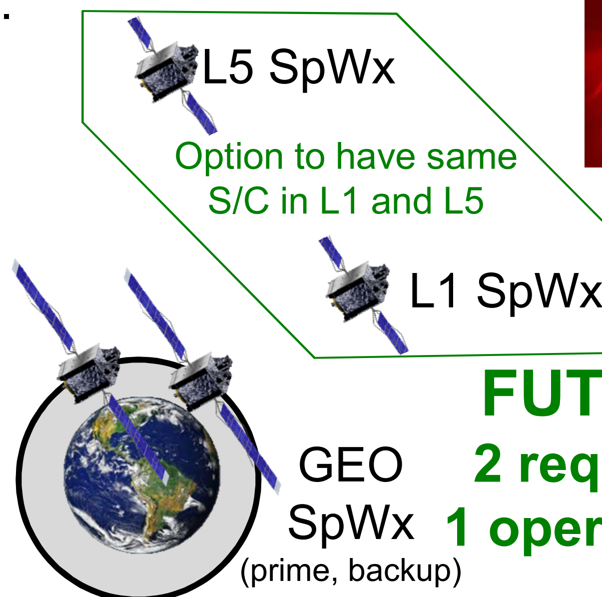


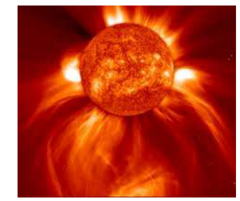
Benefits of Free-Flyer: Less complex and lower cost than traditional GOES and also greater flexibility for multiple, different orbits

- All of the traditional GOES SpWx sensors can be inexpensively accommodated on a smaller spacecraft that offers flexibility for more launch opportunities and to different locations such as GEO, L1, and/or L5.

TODAY – 3 required, 2 operational

GOES West | GOES Backup | GOES East





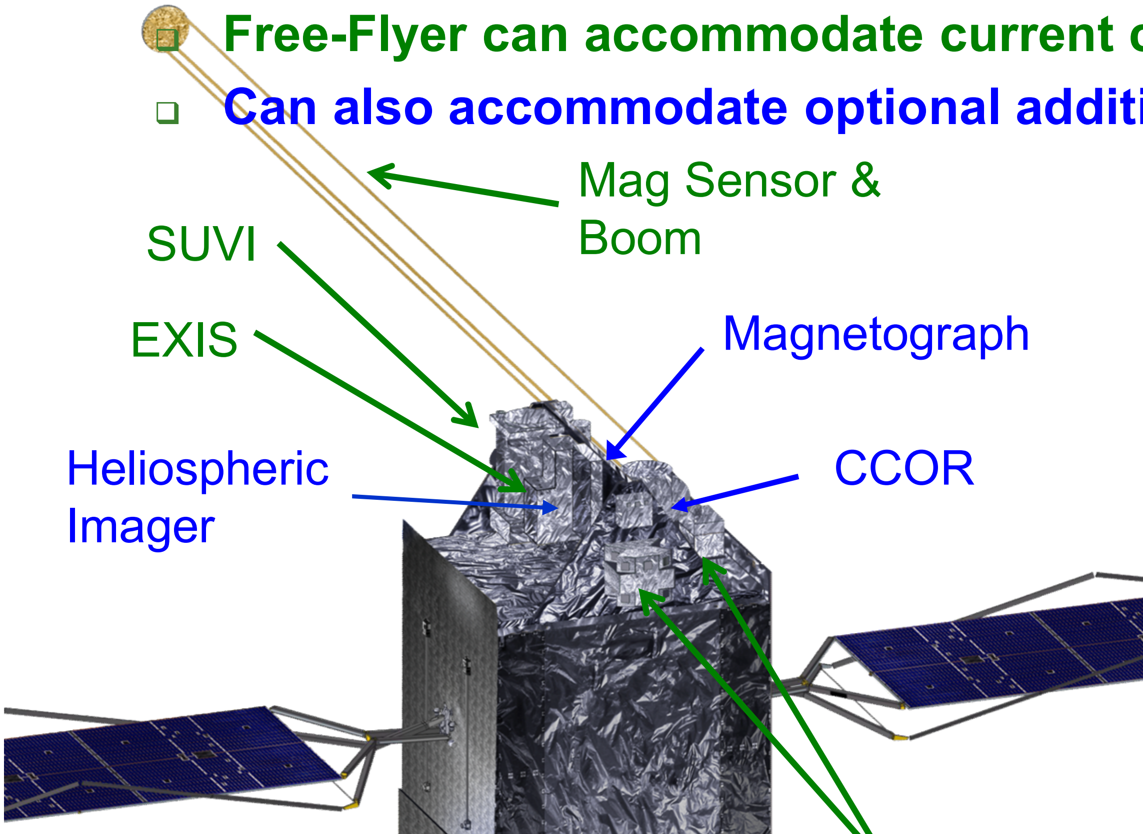
FUTURE
2 required, 1 operational

Fewer (2 instead of 3) spacecraft are needed in GEO for SpWx operations. One provides the prime measurements, and the second is backup.

Separate, singly focused missions are less complex, can be more efficiently managed, and can be lower cost.

GOES-VW Free-Flyer includes same SpWx Sensors as GOES-R but on Smaller Spacecraft

- **No loss of SpWx measurements:**
  - **Free-Flyer can accommodate current complement of SpWx sensors**
  - **Can also accommodate optional additional SpWx sensors**



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EXIS
Solar EUV & X-ray
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In-situ Energetic
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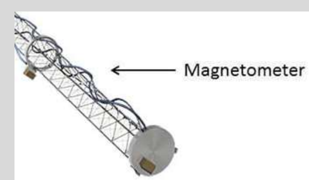


Figures are from GOES-R Fact Sheets

Additional Instrument and Orbit Options

Compact Coronagraph (CCOR)

- NRL has developed the CCOR for NOAA for observing solar wind and CME outflows and giving several day warning of CME geo-effectiveness
- Observes visible light corona outflow from 3.7 R_S to 17 R_S
- NOAA SWPC currently uses SOHO coronagraph data for operations

Compact solar Magnetograph (CMAG)

- ESA Solar Orbiter Polarimetric and Helioseismic Imager (PHI) is a small magnetograph and is an example for CMAG
- Observes solar magnetic fields that are important for forecasting flares and CMEs based on active region complexity

Heliospheric Imager (HI)

- NRL has developed 4 versions of the Heliospheric Imager for SMEI, STEREO, SO, and SPP
- Observes solar wind and CME flow from about 15 R_S to 1 AU
- From L5, the HI could observe the flow of a CME from the Sun to all the way to Earth

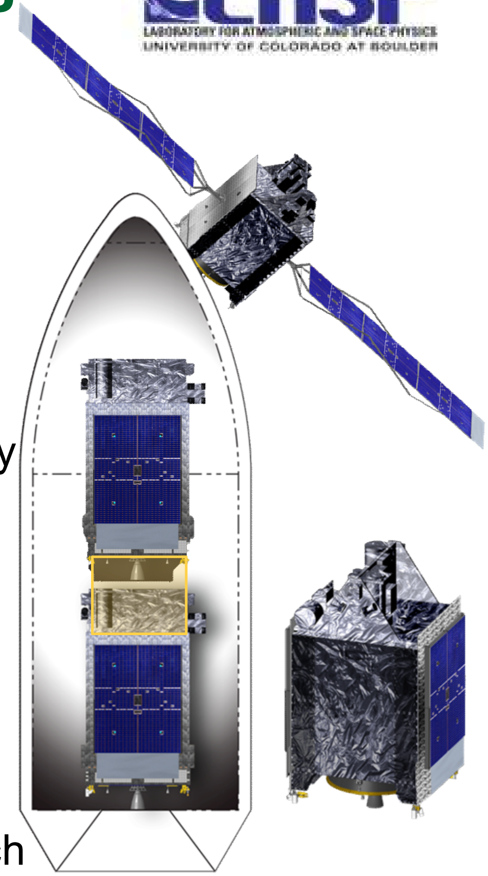
GOES-VW Free-Flyer → L1 / L5

- The Free-Flyer could also be flown to L1 or L5 for different space weather monitoring viewpoint than GOES GEO location
- The optional instruments could be more important for L1/L5 mission

The spacecraft has the capacity to accommodate additional instruments

Free-Flyer can Maintain Capability and High Reliability for SpWx Operations

- The smaller Free-Flyer supports the current Space Weather instruments and with increased capability to accommodate a coronagraph, heliospheric imager, and/or magnetograph for enhanced space weather monitoring
- Program risks are reduced with the use of a proven GEO communication bus
  - 35 GEOStar satellites from Orbital ATK have been successfully built and launched for more than 22 worldwide customers to date
  - 6 more currently under contract to build
- The GEOStar-3 bus is designed for a life time of more than 15 years, overall system reliability is greater than 0.85 at 15 years
  - Implements fully redundant avionics
  - Contains sufficient propellant to compensate for 3-sigma launch vehicle dispersion and 15 years of station-keeping
  - Maintains power margin at end of life (EOL) with 2 failed strings
  - Provides battery depth of discharge (DOD) no less than 80% at EOL including one failed string per pack



Orbital ATK's GEOStar satellites can be launched in a single (dedicated) or dual launch configuration (with modification).

Free-Flyer is simpler and smaller, but not losing capability or reliability.

Management Model based on SORCE

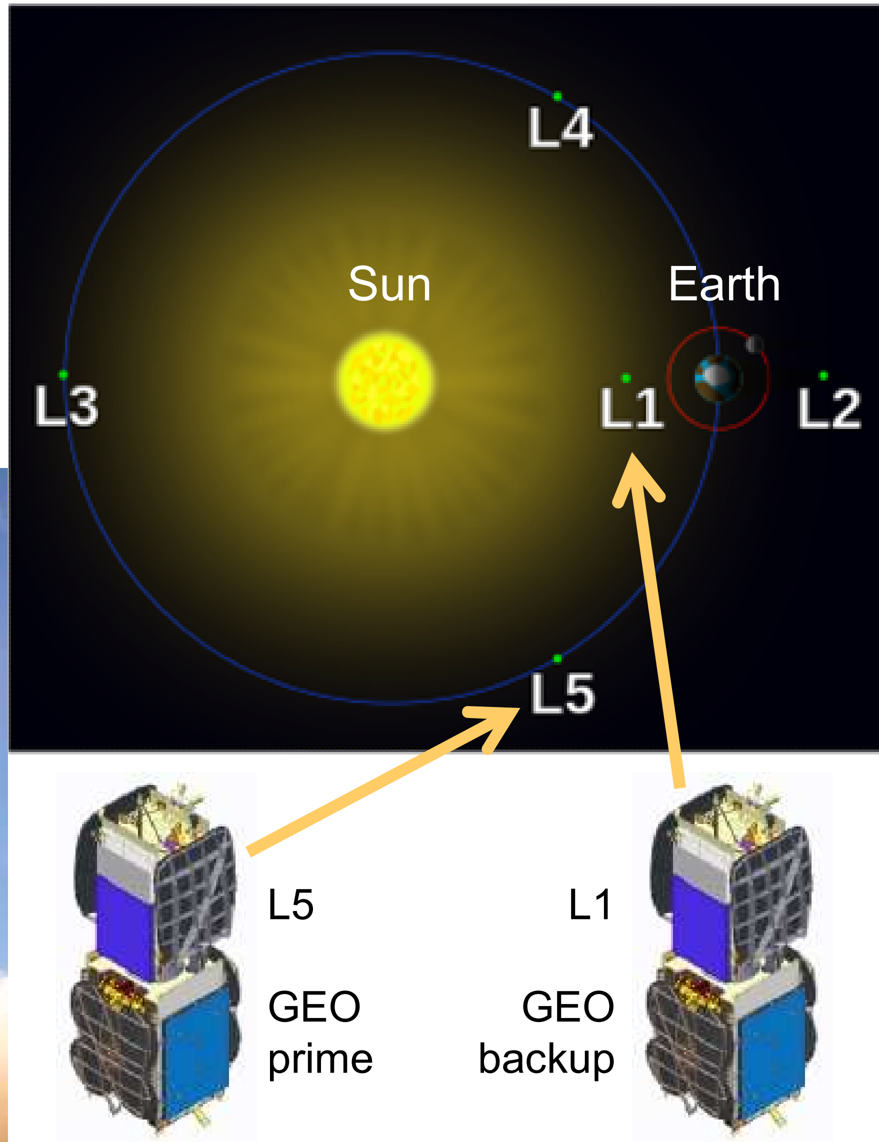
- **LASP has a long history of being the prime contractor for small missions including the SME mission in the 1980s, the SNOE mission in the 1990s, and more recently the SORCE and AIM missions that are still operating today.**
- <u>SORCE Program Development Model Highlights</u>
  - Written up in the November 2015 *National Geographic* as one of NASA's ten most critical space missions for collecting data on climate, weather, and natural disasters.
  - A model for technical capability, reliability, performance, and achievement of mission goals, as well as for management efficiencies and cohesive teamwork between contributing partners that produced an end product ahead of schedule and under planned cost.
  - Successfully operated from the LASP Mission Operations Center from launch in 2003 to present time (13+ years)
  - SORCE is a small satellite carrying four LASP-built scientific instruments that measure the total solar irradiance (TSI) and solar spectral irradiance (SSI).
  - Three axis stabilized spacecraft, with solar and stellar pointing capability, developed by Orbital ATK (based on LEOStar-2 bus design) for a 5-year mission.

SORCE

Option for Expanded SpWx Ops from L1 or L5

First Launch with two SpWx Free-Flyers

1) GEO prime
2) L5



Second Launch with two SpWx Free-Flyers

1) GEO backup
2) L1

Summary and Recommendation

- The “Free-Flyer” concept for the NOAA SpWx measurements:
  - Allows for independence of SpWx priorities from Wx sensor priorities
  - Can be implemented in a simpler, more streamlined, less-expensive way than GOES
  - Has flexible design to add optional SpWx sensors and to launch to additional orbits such as to L1 and/or L5
  - Is a mature concept, both technically and programmatically

Recommendations

- Pre-formulation phase trade studies are recommended to assess cost, technical feasibility, and benefits of implementing a GOES-VW SpWx Free-Flyer. Key trade studies include:
  - Orbit locations of GEO, L1, and L5
  - SpWx instrument complement
  - Spacecraft and launch options
  - Ground system architecture and implementation

BACKUP SLIDES

Comparison of GOES-R and GOES-VW Reimagined with SpWx Free-Flyer Mission

<u>GOES-R</u>

- GOES-R is an **agency led mission**
- **3** on-orbit large satellites
  (East, West, spare)

<u>GOES-VW SpWx Free-Flyer</u>

- GOES-VW Free-Flyer is a **prime-contractor led mission**
- **2** on-orbit small satellites
  (prime, backup)

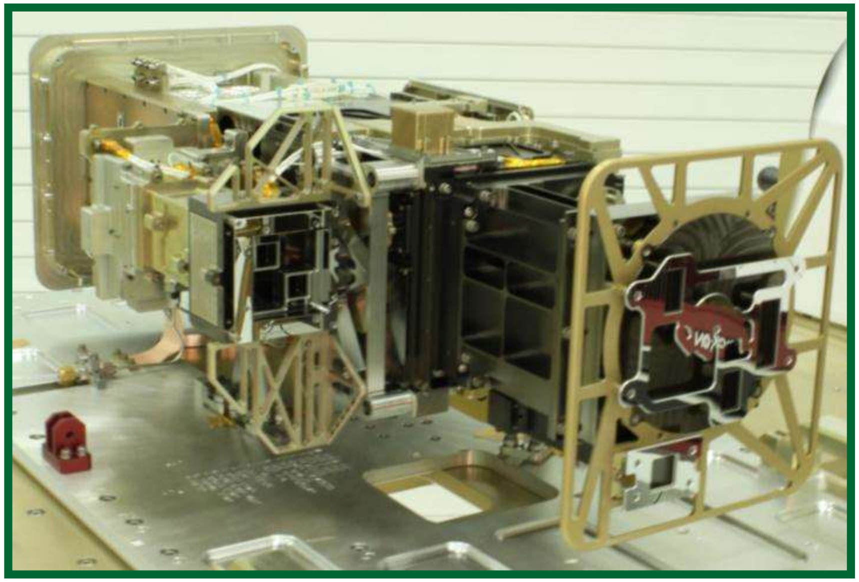
2 Free-Flyers could be launched on one Launch Vehicle with simple modifications to the GEOStar-3

Instruments – EUV & X-ray Irradiance Sensors

LASP
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS
UNIVERSITY OF COLORADO AT BOULDER

Key Requirements and Performance

Observation	Requirement	Performance
X-Ray Irradiance	0.05-0.4 nm: 10^{-9}-10^{-3}W/m^2; 0.1-0.8 nm: 10^{-8}-4x10^{-3}W/m^2	0.05-0.4 nm: 4x10^{-10}-2x10^{-2}W/m^2; 0.1-.8 nm: 6x10^{-10}-1.5x10^{-2}W/m^2
EUV Irradiance	0-127 nm: 0.1*Solar Min to 10*Solar Max	discrete lines to models 0-127 nm; meets req. dynamic range
Accuracy	XRS: 10% EUVS: 20%	XRS: <7% EUVS: <20%
Cadence	XRS: 3 sec EUVS: 30 sec	XRS: 1 sec EUVS: 30 sec



Flight Heritage

Instrument	Flight	Institution
GOES-R EXIS	1st Launch Oct 2016	LASP
SDO EVE	2010-present	LASP
SORCE	2003-present	LASP
TIMED SEE	2001-present	LASP

EXIS Metrics	
Mass	29 kg
Power	31 Watts
X-Band Data Rate	9.7 kbps
L-Band Data Rate	0.7 kbps

Instruments – Solar UltraViolet Imager

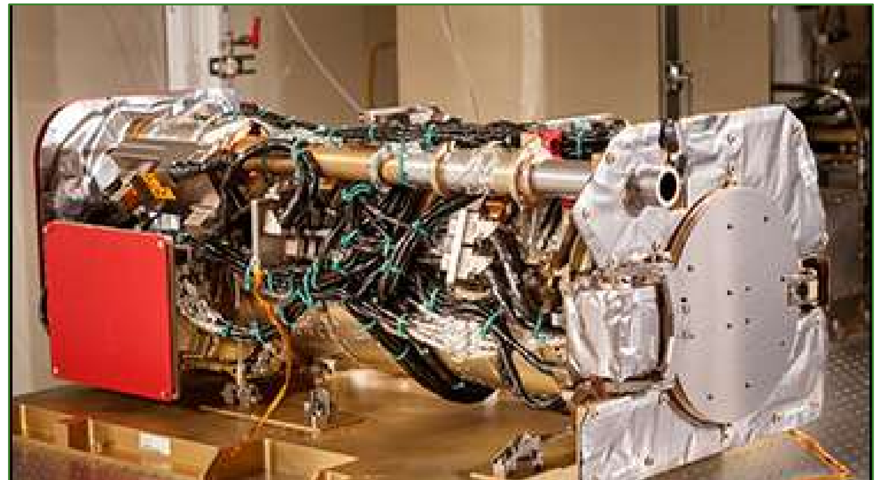
Key Requirements and Performance

Observation	Requirement	Performance
Coronal Holes	Location & Morphology	Fe XV 28.4 nm
Flares	Location & Morphology	Fe XVIII 9.4 nm & Fe XX 13.3 nm
CMEs & Active Regions	Coronal Dimming AR Complexity	Fe IX 17.1 nm & Fe XII 19.5 nm
Filaments & Quiet Regions	Location & Complexity	He II 30.4 nm
Angular Res.	< 5.0 arcsec	2.5 arcsec / pixel
Cadence	< 5 minutes for 3 spectral channels	< 4 minutes for all channels

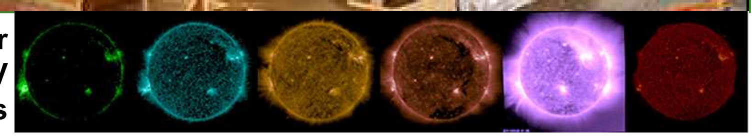
Flight Heritage

Instrument	Flight	Institution
GOES-R SUVI	1st Launch Oct 2016	LMSAL
GOES-N SXI	2010-present	LMSAL
SDO AIA	2010-present	LMSAL

GOES-R SUVI



Solar EUV Images



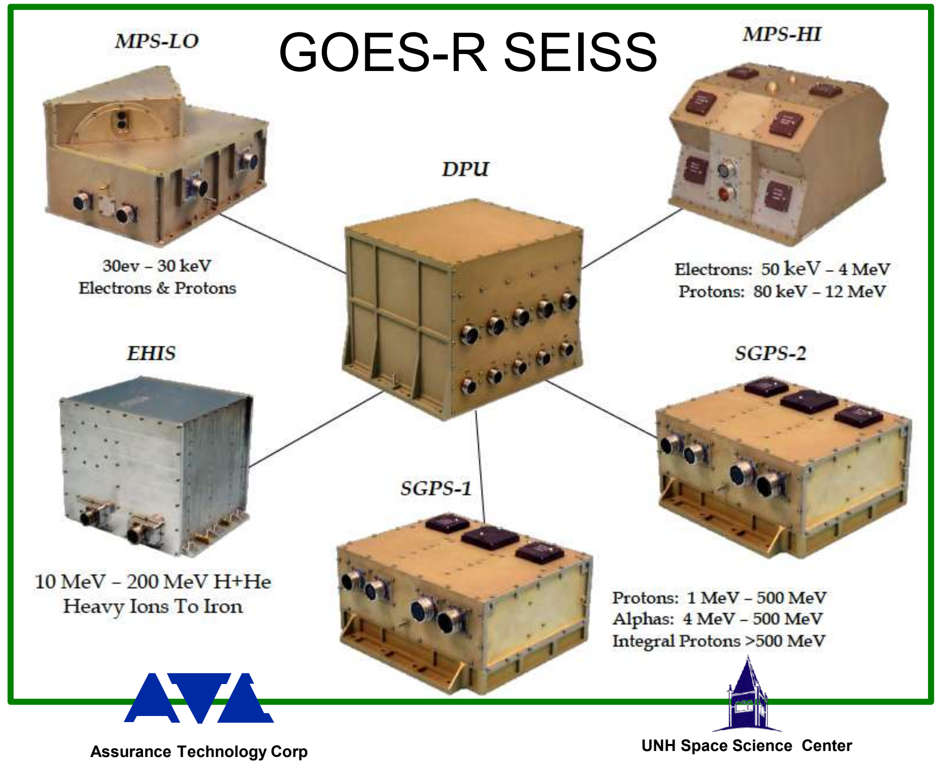
SUVI Metrics	
Mass	66 kg
Power	172 Watts (peak) 144 Watts (operational)
X-Band Data Rate	3.5 Mbps
L-Band Data Rate	1 kbps

Figures from LMSAL SUVI

Instruments – Space Environment In-situ Suite

Key Requirements and Performance

Observation	Requirement	Performance
Low Energy Electrons & Protons	30eV – 30keV 15 energy bands 5 angular views 30 sec cadence	30eV – 30keV 15 energy bands 12 angular views 1 sec cadence
High Energy Electrons & Protons	50keV – 4MeV 7 energy bands 5 angular views 30 sec cadence	50keV – 4MeV 11 energy bands 5 angular views 1 sec cadence
Very High Energy Protons	1MeV – 500MeV 10 energy bands 2 angular views 60 sec cadence	1MeV – 500MeV 10 energy bands 5 angular views 1 sec cadence
Energetic Heavy Ions	10-200MeV/ion 5 energy bands 1 direction 5 min cadence	10-200MeV/ion 5 energy bands 1 direction 5 min cadence



Flight Heritage

Instrument	Flight	Institution
GOES-R SEISS	1st Launch Oct 2016	ATC
GOES-N	2010-present	ATC
DMSP SSJ5	1999-present	ATC

SEISS Metrics	
Mass	74 kg
Power	53 Watts
X-Band Data Rate	24 kbps
L-Band Data Rate	1 kbps

Figure from ATC SEISS team

Instruments – Magnetometer & 8-m Boom

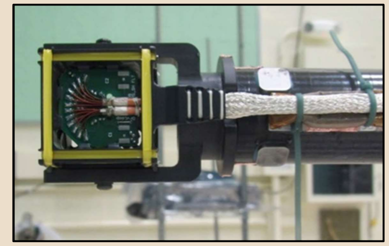
Key Requirements and Performance for measuring the magnetic field

Parameter	Requirement	Performance
Sensitivity	0.1 nT	0.1 nT
Resolution	0.016 nT	0.01 nT
Range	+/- 1000 nT	+/- 1000 nT
Cadence	0.5 sec	0.4 sec
Axes	3-axis	3-axis

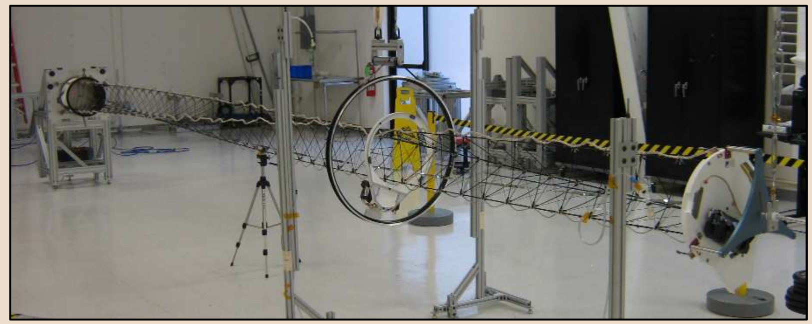
Flight Heritage

Instrument	Flight	Institution
GOES-R/S/T/U Mag Boom	1st Launch Oct 2016	Orbital ATK
GOES-N/O/P Mag Boom	2006-present	Orbital ATK
MMS AFG & DFG Magnetometers	2015-present	UCLA

MMS AFG Magnetometer Sensor



GOES-R Magnetometer Boom



Mag Sensor + Boom Metrics	
Mass	25 kg
Power	5 Watts
X-Band Data Rate	1 kbps
L-Band Data Rate	1 kbps

Figures are from GOES-R website & UCLA